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AUTOMATIC RECORDER OF THE WAVEFORMS OF ATMOSPHERICS

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ABSTRACT. An automatic atomosphorics recorder was constructed for recording the electric field-changes during the various lightning discharges. It consisted of several suitable units which were designed for obtaining complete, accurate and non-overlapping oscillograms with minimum waste of the recording film. The details of the component units and of the various associated circuits are described in the paper.

INTRODUCTION

For studying the waveforms of atmospherics, an automatic recorder was designed and constructed in the laboratory. The main object was to obtain a full and faithful record of the electric field-changes during the various lightning discharges. It was therefore necessary to set up several suitable units for delineating and photographing the electric field-changes on the fluorescent screen of a cathoderay oscillograph after suifficient amplification without distortion and adequate time-resolution. Suitable trigger circuits were constructed and employed for the intensity-modulation of the oscillograph. Necessary circuits were set up for recording the initial part of the electric field variation which was of small magnitude. Arrangements were also made for avoiding overlapping of the oscillograms and for the automatic recording of the electric field-changes during the lightning discharges.

COMPONENT UNITS IN THE ATMOSPHERICS RECORDER

The various component units were not constructed in their final form at the same time. Some of the circuits were developed by stages after testing the performance of the entire equipment. No attention is, therefore, paid to the chronological sequence in describing the various associated circuits of the different units.

In what follows, we shall describe the different units of automatic atmospherics waveform recorder.

1. AERIAL UNIT

In the earlier experimental studies of the waveforms of atmospherics, an open-air horizontal aerial of effective height, 12 metres, and self-capacity, 265 $\mu\mu F$, was used as the receiving antenna, but in the later investigations, a smaller aerial of similar type with an effective height of 4 metres and self-capacity of 100 $\mu\mu F$. was employed. The vertical leads from the aerial were led into the observation room through proper insulators and they were well shielded to reduce the 50-cycles hum from the power mains.

A resistance R of $1k\,\Omega$ and a condenser C_1 of capacity, $0.001\mu F$, (figure 1 were placed in series with the aerial, so that the latter was rendered aperiodic

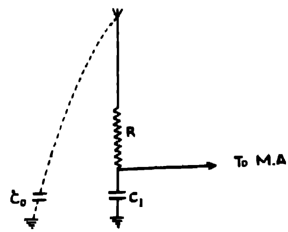


Fig. 1. Aerial unit.

with a time-constant which was small in comparison with the duration of the atmospherics.

2. MAIN AMPLIFIER

A wide-band, R-C coupled, Class A, three-stage voltage-amplifier, having a flat frequency-response from 100 c/s to 100 kc/s was constructed and used as the main amplifier. Two 6AC7 (V_1 and V_2) valves, each having a high figure of merit were used in the first and the second stage of the amplifier, whereas a power pentode, 6AG7 (V_3), was found very suitable as an output valve. As these high-transconductance pentodes are quite microphonic, the whole amplifier was fitted with rubber cushions in order to protect it from mechanical vibrations. Due care was taken about the lay-out and the wiring of the amplifier to reduce the pick-up of the 50-cycles hum by the amplifier.

For the manual control of the total gain (80 db) of the amplifier, two calibrated carbon potentiometers were used as grid-leak resistances in the first and the third stage of the amplifier. The phase-shift distortion measured oscillographically and the amplitude distortion determined by the 'fundamental supression method' were found to be negligible in the useful frequency range of the amplifier.

The detailed circuit diagram of the amplifier is shown in figure 2.

3. SQUARE-WAVE TRIGGER UNIT

For recording the oscillograms without over-lapping, the intensity- modulation of the cathode-ray oscillograph required for making it operative only on the arrival of the atmospherics, was effected with the help of a positive square-wave trigger circuit in the following manner :

A part of the output voltage from the main amplifier adjustable by means of a potentiometer was fed into a single stage $R-C$ coupled triode (V_4—6SC7) amplifier, the output of which was connected to a cathode-follower phase-inverter

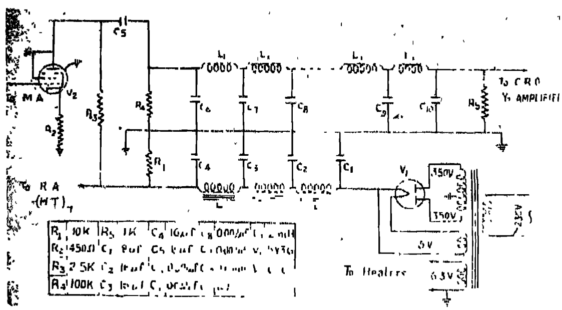
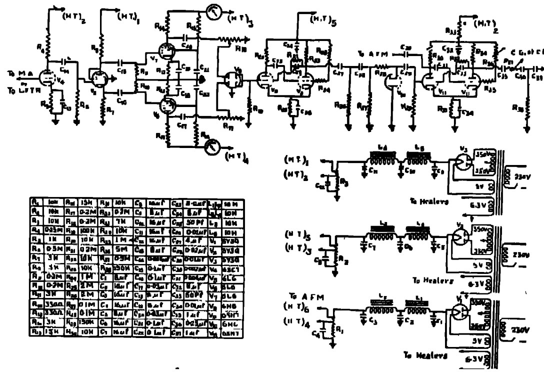


Fig. 2. Main amplifier.

(V_5—6L6). The input of the latter could thus be adjusted to any desired level without disturbing the gain of the main amplifier. The balanced output voltages (with respect to the ground) from the phase-inverter were so fed into a double-diode (V_8—6H6) *via* two peak-clippers (V_6, V_7—6L6), that whatever might be the polarity (positive or negative) and the amplitude of the initial portion of the atmospherics pulse, a positive voltage of almost fixed value (nearly 40 volts) was developed between the cathode of the diode and the ground. The output voltage from this double diode was then applied to a univibrator (V_9—6SN7) which remained quiescent until its action was initiated by a positive voltage of about 40V at its input. The univibrator was so arranged as to have a *quasi*-stable state of controllable time from 0.5 to 2.0 seconds. The rectangular voltage output from the univibrator was differentiated and then applied to a clamping circuit with a diode, (V_{10}—6H6), from which only the sharp positive pulse was derived which was utilised to trigger another univibrator (V_{11}—6SN7) the output of which gave a rectangular pulse of about 40V with a *quasi*-stable state of about 6 milli-seconds. This was applied to the modulating grid (usually kept at a high negative potential with respect to the ground) of the cathode-ray oscillograph thus allowing in cathode-ray beam to reach its full brilliance during the *quasi*-stable state of the pulse.

During the *quasi*-stable state of the first univibrator, lasting for a time of 0.5 to 2.0 seconds, no further intensity-modulating pulse could be derived from the subsequent atmospherics. The entire triggering circuit would thus have a quiescent time of the same duration after each triggering pulse, preventing thereby overlapping of oscillograms.

The detailed circuit diagram of the whole square-wave triggering unit is shown in figure 3.



R_1	10K	R_{16}	15K	R_{31}	10K	C_8	16µF	C_{23}	8·0µF	L_1	10 H
R_2	10K	R_{17}	0·2M	R_{32}	0·3M	C_9	8µF	C_{24}	8µF	L_2	10H
R_3	10M	R_{18}	0·2M	R_{33}	7M	C_{10}	16µF	C_{25}	50 PF	L_3	10H
R_4	0·25M	R_{19}	100K	R_{34}	10M	C_{11}	16µF	C_{26}	0·01µF	L_4	10H
R_5	1M	R_{20}	10K	R_{35}	1M	C_{12}	16µF	C_{27}	4µF	V_1	5Y3G
R_6	0·5M	R_{21}	0·3M	R_{36}	5M	C_{13}	8µF	C_{28}	0·02µF	V_2	5Y3G
R_7	3K	R_{22}	10K	R_{37}	0·5M	C_{14}	[illegible]	C_{29}	0·01µF	V_3	5Y3G
R_8	3K	R_{23}	10K	R_{38}	250K	C_{15}	0·1µF	C_{30}	0·002µF	V_4	6SC7
R_9	0·3M	R_{24}	1M	C_1	8µF	C_{16}	0·1µF	C_{31}	0·004µF	V_5	6L6
R_{10}	0·7M	R_{25}	2M	C_2	16µF	C_{17}	0·05µF	C_{32}	8µF	V_6	6L6
R_{11}	3K	R_{26}	2M	C_3	16µF	C_{18}	8µF	C_{33}	50PF	V_7	6L6
R_{12}	330Ω	R_{27}	0·1M	C_4	16µF	C_{19}	8µF	C_{34}	0·01µF	V_8	6H6
R_{13}	330Ω	R_{28}	0·1M	C_5	8µF	C_{20}	0·05µF	C_{35}	1µF	V_9	[illegible]
R_{14}	3K	R_{29}	150K	C_6	16µF	C_{21}	0·1µF	C_{36}	0·25µF	V_{10}	6H6
R_{15}	15K	R_{30}	10M	C_7	16µF	C_{22}	0·1µF	C_{37}	1µF	V_{11}	6SN7

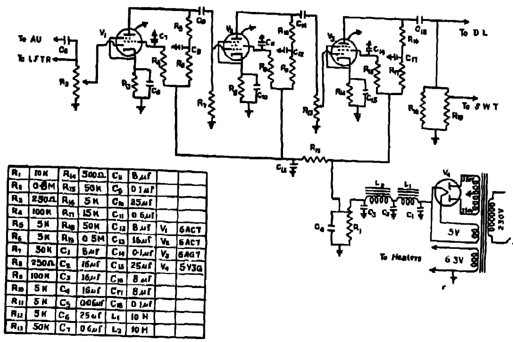
Fig. 3. Square-wave trigger unit.

4. DELAY LINE UNIT

As a square-wave trigger unit would require a positive voltage of predetermined value, there must be a definite time-lapse between the arrival of the atmospherics pulse and the restoration of the brilliancy of the cathode-ray beam, the magnitude of the time delay depending upon the initial rise-time of the wave-form of an atmospherics pulse. Hence in order to restore the initial portion of the wave form lost in the oscillographic record, before triggering, it was necessary to delay the signal by about $60\mu s$, whereas the undelayed signal was used for triggering the square-wave trigger unit.

The delay-line was of a negligible rise-time and was of the form of a low-pass, ladder-type filter having 30 sections. The theoretical cut-off frequency of the delay line was kept as high as 150 kc/s, so that negligible phase distortion would be introduced in the useful frequency spectrum of the transmitted pulse. Because of the low normal characteristic impedance of the delay-line, an impedance-matching amplifier was introduced between the delay-line and the main amplifier. The impedance-matching amplifier was essentially a cathode-degenerated *R-C* coupled voltage-amplifier with a very small coupling resistance. A high transconductance valve (6L6), used as a triode, was found suitable as an amplifier tube, since it could accommodate a large signal voltage with negligible distortion in the output voltage.

The circuit diagram of the delay-line unit is shown in figure 4.



R_1	10K	R_{14}	500Ω	C_8	8μF		
R_2	0·8M	R_{15}	50K	C_9	0·1μF		
R_3	250Ω	R_{16}	5K	C_{10}	25μF		
R_4	100K	R_{17}	15K	C_{11}	0·6μF		
R_5	5K	R_{18}	50K	C_{12}	8μF	V_1	6AC7
R_6	5K	R_{19}	0·5M	C_{13}	16μF	V_2	6AC7
R_7	50K	C_1	8μF	C_{14}	0·1μF	V_3	6AG7
R_8	250Ω	C_2	16μF	C_{15}	25μF	V_4	5Y3G
R_9	100K	C_3	16μF	C_{16}	8μF		
R_{10}	5K	C_4	16μF	C_{17}	8μF		
R_{11}	5K	C_5	006μF	C_{18}	0·1μF		
R_{12}	5K	C_6	25μF	L_1	10H		
R_{13}	50K	C_7	0·6μF	L_2	10H		

Fig. 4. Delay line unit.

5. OSCILLOGRAPH UNIT

A Cossor double-beam oscillograph (Model No. 1035) with a cathode-ray tube of flat blue fluorescent screen was employed very successfully for recording the waveforms of atmospherics. Usually the atmospherics signal from the delay-line was given to the Y_2-amplifier of the oscillograph.

Puckle's hard-valve linear time-base of the oscillograph was found suitable as X-sweep, because of its perfect linearity in the useful range of the sweeps. The time-range switch of the oscillograph would allow the variation of the transverse speed, the duration ranging from 15 microseconds to 150 milliseconds. The required transverse speeds were previously calibrated with the help of a standard audio-oscillator, employing the frequency comparator principle. The fly-back suppression was made inoperative in order to trace the course of the horizontal lines in the raster arrangement.

6. RASTER ARRANGEMENT

In the raster arrangement there was a linear time-base using a thyratron (V_2—884 R.C.A.) followed by a two-stage *R-C* coupled amplifier. The first stage of the latter worked as a voltage-amplifier (V_3—6AC7) and the second stage was an impedance-matching amplifier (V_4—6L6, used as a triode) similar to the one which was used in the delay-line unit. The linear time-base of the cathode-ray oscillograph would by itself deflect the cathode-ray spot horizontally. When the raster linear time-base with a period which was an integral multiple of that of the horizontal sweep was applied simultaneously to the vertical deflector plates of the cathode-ray oscillograph, several horizontal lines, one above another, were swept out and exhibited on the fluorescent screen of the oscillograph. Since the output from the main amplifier was applied to the same vertical deflector plates of the oscillograph through the delay-line unit, any electrical field-change due to an atmospheric pulse would produce a corresponding vertical deflection on the raster lines.

The purpose of the raster arrangement was to provide for the longer duration of the oscillographic records without overlapping, at the same time permitting a greater time-resolution in the waveform observations.

The detailed circuit diagram of the above arrangement is shown in figure 5.

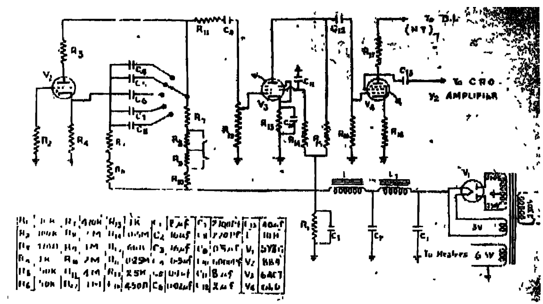


Fig. 5. Raster arrangement

7. AUTOMATIC FILM-MOVING UNIT

The function of the automatic film-moving unit was to move the photographic film forward through a distance of about 2 cms after each exposure and its working may be briefly explained as follows :

The intensity-modulating pulse derived from the square-wave trigger unit was differentiated and applied to a diode-clamping circuit, the output of which gave a positive pulse which was used to trigger a univibrator. A solenoidal relay placed in the plate circuit of the cut-off valve of the univibrator was energised during its *quasi*-stable state, thus completing the power supply of a capacitor-

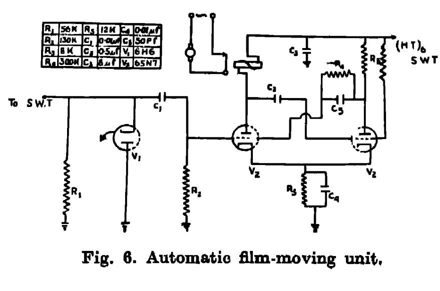


Fig. 6. Automatic film-moving unit.

type motor which was free from electrical interference and fitted with a reducing gear system. The motor-drive was transmitted to the spindle of the camera unit through a friction-clutch, so that the exposed film could be automatically moved forward about 2-cms distance during the *quasi*-stable state of the univibrator.

The circuit diagram of the automatic film-moving unit is shown in figure 6.

8. CAMERA UNIT

The camera unit consisted of a F/1.9 lens of 10.4 cm focal length with which the oscillograms could be photographed continuously, either manually or automatically, on a perforated 35 mm film with the image reduction ratio of 3.6. The exposed film moved forward by the conventional sprocket-drive method. Actually the body of the camera unit contained a main casting locating the driving sprockets, the guide rollers and a film driving spindle which could be coupled to the motor-drive unit.

While taking observations, the camera shutter was kept open and the fluorescent screen of the oscillograph kept blank with the help of the 'intensity-control' knob, so that the oscillograph would be intensity-modulated only on the arrival of the atmospherics, with the result that the oscillograms would be exposed to the film without any delay. After each exposure, however, the exposed film would move forward automatically by the automatic film-moving unit, so that the unit would be ready for recording the subsequent oscillogram.

9. LOW-FREQUENCY TUNED AMPLIFIER

This unit was essentially a narrow-band low-frequency tuned receiver having a maximum gain of 65 db. The receiver was a transformer-coupled amplifier (V_2—6AC7) with a tuned secondary, tunable to any frequency between 14 kc/s to 18 kc/s. The output of this stage was coupled to a conventional *R-C* coupled amplifier (V_3—6SJ7). A cathode-follower (V_1—6SJ7) with a step-attenuator as an input stage to the amplifier provided a high input impedance to the receiver, so that the receiver when coupled to the aerial unit in parallel with the main amplifier would offer negligible shunting effect to the main amplifier.

The purpose of the unit was to develop any rapid electrical variations, in the initial portion of an atmospheric pulse, to an extent sufficient to trigger the square-wave trigger circuit for intensity-modulating purposes. This kind of triggering was found at times advantageous (especially when the electrical noise in the locality of the equipment was higher than usual) over the usual method of triggering which has already been described. Being a tuned receiver, it was capable of discriminating the low-frequency electrical noise from the atmospherics pulses, so that the high electrical noise was unable to trigger the square-wave trigger unit. As a consequence the wastage of the film was avoided.

The circuit diagram of the low-frequency tuned amplifier is shown in figure 7.

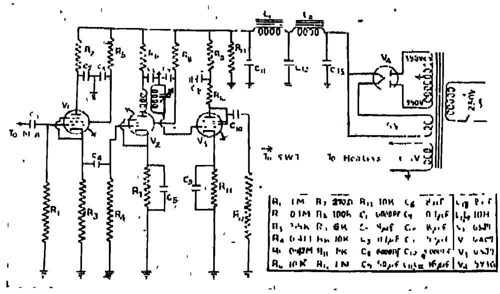


Fig. 7. Low frequency tuned amplifier.

10. TRANSIENT GENERATOR UNIT

In this unit, a condenser was charged and then discharged through a suitable inductance in series with a suitable resistance by means of make-and-break key. The L-C-R of the circuit was so adjusted that the discharge was oscillatory giving a *quasi*-period of about a millisecond. This unit was found very useful for periodical testing of the performance of the automatic atmospherics recorder.

A block diagram of the automatic atmospherics waveform recorder, indicating its various units is shown in figure 8. A few oscillograms representing electric field-changes during lightning discharges are shown in figure 9.

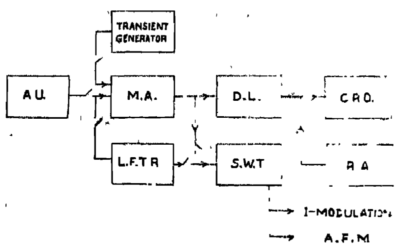


Fig. 8. Block diagram of the automatic waveform recorder.

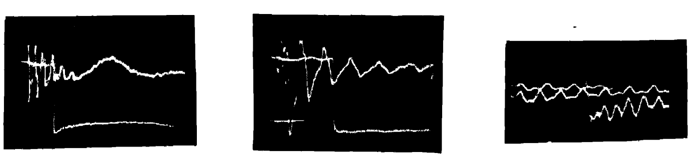


Fig. 9. Oscillograms representing electric field-changes during lightning discharges.

CONCLUSION

The automatic atmospherics waveform recorder described above was employed successfully in the investigations on the wave-forms of atmospherics since 1952. A preliminary report of the recorder in the early stage of its development was already published by the author (Tantry, 1952). The construction of the recording equipment was initiated as early as July 1950, so that some of the circuits which are in some respects similar to those employed by Clarke and Mortimer (1951) and Caton and Pierce (1952) were designed almost about the same time.

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